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RESEARCH PAPER

Geographic variation and provenance selection for bamboo wood properties in *Bambusa chungii*

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Abstract: Using 3-year-old culms of 8 provenances of *Bambusa chungii* from Guangdong, Guangxi and Hainan Provinces, the indexes of wood properties, such as fiber dimensions and chemical composition were investigated and analyzed by the methods of Analysis of variance and correlation coefficient to reveal the geographic genetic variation situation. The results showed that there are significant differences between fiber length, fibrin and 1% NaOH extraction contents of *B. chungii* from 8 provenances; moreover, the fiber length and fiber length/width ratio had a decreasing change pattern with geographic variation from the south to the north in altitude (from high to low in elevation). The heritabilities for fibrin, fiber length, 1% NaOH extractive, lignin and fiber length/width ratio were 0.7, 0.84, 0.54, 0.38 and 0.13, respectively. A significant negative correlation was found between 1% NaOH extraction, benzo-alcohol extraction contents and bamboo culm yield, whereas there was a significant positive correlation between fibrin contents and bamboo wood yield. Besides, a close correlation was detected between fiber dimensions indices and bamboo growth or bamboo wood yield. Finally, three provenances with high qualities and culm yield, i.e. Huaiji, Xinyi and Guilin, were selected as superior sources based on principal component analysis.

Keywords: *Bambusa chungii*; bamboo wood property; pulp-bamboo; geographic variation; provenance selection

Introduction

Paper industry has been developing rapidly in China. At present, China ranks in the third place at world level for total paper and paper-board production, only behind the United State of America and Japan (Gan 2002). However, the paper industry of China is facing a challenge due to the shortage in raw materials, which has forced major imports from foreign countries. It is difficult for China to develop the paper industry only depending on the wood pulp stands because of the shortage of annual wood stock output (Ma et al. 2004). Fortunately, China is rich in bamboo resources. The indexes of bamboo wood fiber and chemical components show that bamboo wood has a good pulp potential. The bamboo wood can be used to make bamboo pulp or bamboo-wood mixed pulp to produce various types of paper. Using bamboo as partially substitute for wood could be an effective way for the paper industry to overcome the shortage of wood pulp.

Many studies showed that different bamboo species have obvious differences in bamboo wood properties and chemical components. Most bamboos, especially sympodial bamboos, are superior materials for papermaking (Ma et al. 2004; Wang et al. 1999; Hui et al. 1993). *Bambusa chungii*, belonging to the *Bambusa* genera, is an important sympodial bamboo species in the south of China, being distributed mainly in Guangdong, Guangxi, Hainan, and Fujian provinces. *B. chungii* has high economic values and can be used as raw material for strip and paper-making. Xinyi county of Guangdong Province, with an area of 20×10^3 ha, has the largest distribution of *B. chungii*.

Studies on wood properties in wood plants had demonstrated that there were abundant genetic variations at different genetic control levels (Wright et al. 1993; Matheson et al. 1986). However, few studies have been reported on bamboo wood properties, although bamboo has multi uses and high economic values. In the present study, the properties of fiber dimensions and chemical components in bamboo wood were investigated from 8 provenances of *B. chungii* with 3-year-old culms. The objective of this study was to find out the geographic genetic variations in bamboo wood properties and growth traits among the various provenances, and the relationship between genetic variation and their ecological environment factors, so as to improve the effective utilization of the bamboos and to give some useful information to bamboo planters.

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Materials and methods

Bamboo wood material

Bamboo wood samples used in this study were taken from a *B. chungii* provenance test station established with 8 provenances of *B. chungii* at Maoming, Guangdong, in the south of China. In accordance with the natural distribution of *B. chungii*, all samples of the provenances were collected from 8 natural populations in Guangdong, Hainan and Guangxi provinces. Detailed information of the sampling plots is given in Table 1. The distance between two populations was more than 200 km to avoid sampling mother bamboo from the same population, and the distance between two samples was 50 m apart. Mother bamboos were planted at 3 m×4 m spacing in 2001. The experiment was arranged in three randomized complete blocks and each provenance was established in a 12-row clump plots. There were two rows of the same species from local populations as fence surrounding the trial site. No particular silvicultural treatment was performed before the collection of the timber sample.

Table 1. Characteristics of site and climate of eight sampling plots of *Bambusa chungii*

Provenance	Longitude	Latitude	Aaltitude (m)	Annual mean temp. (ºC)	Minimum temp. （ºC）	January monthly mean temp. （ºC）	July monthly mean temp. （ºC）	Annual precipitation （mm）	Relative humidity （%）	Frostless days （d）
Qiongshan, Hainan	110º30′	19º50′	35	23.8	2.8	12.1	28.3	1676.4	85	365
Nanning, Guangxi	108º21′	22º49′	90	21.6	-2.1	12.8	28.2	1304.2	79	360
Guilin, Guangxi	110º30′	24º46′	135	18.9	-2.1	15.6	23.0	1949.5	79	309
Fengkai, Guangdong	111º33′	23º30′	25	20.8	-3.4	11.2	28.6	1420.8	82	355
Huaiji, Guangdong	112º12′	23º50′	90	20.8	-3.9	13.5	28.8	1785.4	80.2	310
Xinyi, Guangdong	110º55′	22º21′	167	22.8	-1.8	13.0	28.0	1800.0	85	340
Zengcheng, Guangdong	113º52′	23º17′	56	21.2	-2.2	13.2	28.2	1967.2	78	359
Qingyuan, Guangdong	113º03′	23º31′	100	21.6	-0.6	12.4	28.8	2173.6	78	351

Environmental conditions of study area

The test site was located in Maoming Forest Park (latitude 21º39´ N, longitude 110º50´E, with an elevation of 23 m above sea level), under south subtropical monsoon climate. The mean annual temperature, minimum temperature,. mean temperature of January, and the mean temperature of July are 23ºC, 2.8ºC, 16.1ºC, and 28.5ºC, respectively. The mean annual precipitation in this area is 1704.9 mm, with relative humidity of 81%. The annual evaporation ranged from 1808.2 to 1993.7 mm; therefore the site has regular droughts every year. The frostless period is over 350 days in the test site. The soil belongs to laterite soil types.

Sample collection of bamboo wood

Six clumps per provenance and sixteen clumps per block were chosen for the study. Totally, 48 culms were felled at the ground level and 10 cm of their top part was cut down. Three bamboo segments (about 40 cm long) from three parts, i.e. at the base, 1.3 m (the standard breast height) above ground level, and top part, were collected from each culm. Selected culms and clumps were free of any physical and mechanical damage and were not infected by any plagues and diseases. All the samples were marked and DBH, height of culm, culm number per clump, clear height and node number under the first branch of the sample culms were measured (Table 2).

Table 2. Information of bamboo samples

Provenance	Height (m)	DBH (cm)	Culms per clump	Clear height (m)	Node number[a]	Thickness of bamboo wall (mm)		
						Culm base	DBH	Culm top
Fengkai, Guangdong	4.58	2.28	24.3	3.7	6.9	0.52	0.34	0.13
Guilin, Guangxi	4.92	2.42	33.9	2.9	6.9	0.52	0.34	0.13
Huaiji, Guangdong	4.87	2.57	32.3	3.1	6.5	0.44	0.28	0.12
Qiongshan, Hainan	3.98	2.13	23.7	2.6	6.7	0.45	0.28	0.11
Nanning, Guangxi	4.95	2.63	31.4	3.1	7.2	0.52	0.35	0.10
Qingyuan, Guangdong	3.70	1.87	56.4	2.5	5.9	0.44	0.26	0.11
Xinyi, Guangdong	4.66	2.62	31.3	3.2	7.4	0.51	0.34	0.12
Zengcheng, Guangdong	4.73	2.52	40.2	2.9	6.7	0.45	0.28	0.12

Notes: "a" is number of nodes below the first branch.

Fiber dimensions of bamboo wood

The sample was boiled several times to break down the fibers. A mixed liquor of hydrogen peroxide (30%–35% concentration) and glacial acetic acid with ratio of 1:1 was used to macerate match-stick pieces from the sample. The unbroken fibers were measured by Kajanni FS-100 fiber automatic analyzer and photos were taken by WV-CP470 microscope camera.

Chemical components of bamboo wood

The bamboo wood samples were cut into pieces and milled into powder to pass through 0.45-μm sieve for analysis. 1% NaOH extraction content, benzo-alcohol extraction content and lignin were measured following the national standards methods GB2677.5-81, GB2677.7-81 and GB2677. 8-81. Cellulose was measured by the Nitric acid-ethanol method.

Yield measurement of bamboo wood

Thirty culms with normal growth and without any physical and mechanical damage were selected. From ground level, DBH and weight of each culm were determined. The data were fit to a Yield equation using a regression model.

Statistical analyses

A mixed linear model was used to estimate variance components.

$$Y_{ijk} = \mu + R_i + F_j + e_{ijk} \tag{1}$$

where, Y_{ijk} is a phenotypic individual observation; μ is the overall mean; R_i is the fixed replication effect; F_j is the random provenance effect with $E(F_j)=0$ and $var(F_j)=\sigma_f^2$; and e_{ijk} is the random residual effect with $E(e_{ijk})=0$ and $var(e_{ijk}) =\sigma_e^2$.

The broad-sense provenance heritability (H^2) was calculated for each trait measured by the following equation.

$$H^2 = (\sigma_f{}^2 - \sigma_e{}^2)/\sigma_f{}^2 \tag{2}$$

The data were analyzed using SAS 8.0. ANOVA. Pearson SAS procedures were used to analyze the variance of each trait. and the correlation coefficients between different traits based on mean value of the data of three parts of the culm (including base, DBH and top of the culm) were calculated. The data were normalized using an arcsine transformation before the statistics analyses.

The power function equation was chosen for fitting the relationship between culm yields(y, fresh weight (kg)) and DBH (X). The regression equation of culm fresh weight-DBH was

$$y=0.1655X^{2.1481}(p<0.001, R=0.9442) \tag{3}$$

The output of a clump could be calculated multiplying the weight of a single culm by the number of culms per clump.

Results and analysis

Variation of fiber dimensions

ANOVA for fiber dimensions and chemical compositions were analyzed in this study (Table 3). Fiber dimensions directly impact the techniques of papermaking and pulp performance. Generally, bamboo wood with fiber of longer length, better flexibility and higher ratio of fiber length to width is regards as better raw material for papermaking. The average length of fiber of *B. chungii* from all the provenances was over 4 mm, which was longer than that of other bamboos (2.09 mm) and broadleaf species (1.04 mm), and even longer than that of some conifers (Qin 2003). The ratio of fiber length to width was very high in *B. chungii*. The range of *B. chungii* fiber length from different provenances varied from 4.25 mm to 4.65 mm, with a significant (p<0.01) difference due to a small coefficient of variation, about 2.3%. No significant differences in fiber width and ratio of fiber length to width of *B. chungii* were found among the provenances. However, significant differences between the two trait indexes (fiber width and ratio of fiber length to width) were observed among all individuals and the coefficients of variance (*COV*) were 19.56% and 16.77% in Qiongshan, Hainan population, respectively. These results suggest that it may be more effective to perform individual selection on fiber dimensions.

Table 3. ANOVA for chemical compositions and fiber dimension of bamboo wood

Index	Mean	Range	CV(%)	Std Dev	*F* value	H^2
1%NaOH extractive(%)	25.30	23.7-26.46	4.95	1.25	2.18^+	0．54
Benzo-alcohol extractive (%)	5.99	5.61-6.44	12.87	0.77	0.37	a
HNO_3-alcohol fibrin (%)	46.23	43.68-50.87	4.42	2.04	3.46^*	0．71
Lignin(%)	22.73	21.31-23.94	5.81	1.32	1.60	0．38
Fiber length(mm)	4.42	4.25-4.65	2.37	0.105	6.34^{**}	0．84
Fiber width(μm)	13.34	12.73-14.08	12.13	1.62	0.27	a
Ratio of L/W	334.92	311.67-373	11.31	37.86	1.15	0．13

Notes: $^{**,*,+}$ indicate statistically significant at 0.01, 0.05 and 0.1 level respectively. a: indicates H^2 for that index can not be estimated.

Variations of chemical components of bamboo wood

Chemical components of bamboo wood have important effect on the quality and performance of paper products. In other words, a higher fibrin, lower lignin and lower extraction would benefit the yield and quality of pulp. Variance analysis for chemical components demonstrated that there are significant differences between fibrin content and 1% NaOH extraction at 5% and 10% level, respectively, but there are no significant differences in lignin and benzo-alcohol extractive among the eight provenances.

Further analysis showed that the fibrin content of bamboo wood fluctuated from 43.68% to 50.87% among the 8 provenances. This change (greater than 7%) indicates that there is a potential for provenance selection. Additionally, the absolute variation value of lignin content was small among provenances and individuals, and benzo-alcohol extract had a large difference among individuals (Table 4). The content of 1% NaOH extract, fibrin and benzo-alcohol extract follows a normal distribution (Fig. 1) indicating that it is also possible to select superior clump with good chemistry for further propagation and utilization.

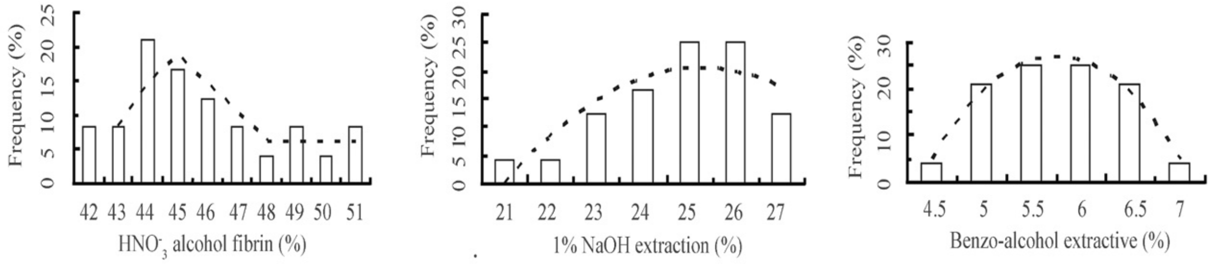

Fig. 1 Frequency distribution of some chemistry properties of *Bambusa chungii*

Table 4. Variation of bamboo wood properties of *B. chungii* within provenances

Provenance.	Fiber length		Fiber width		Ratio of L/W		1%NaOH extractive		Benzo-alcohol extractive		Fibrin		Lignin	
	Mean (mm)	CV (%)	Mean (μm)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)	Mean (%)	CV (%)
Fengkai, Guangdong	4.63	1.92	12.94	11.75	361	12.52	26.31	3.65	5.90	16.1	44.72	1.68	22.26	6.29
Guilin, Guangxi	4.31	0.58	13.74	12.88	316	11.85	25.68	5.72	6.44	7.45	47.69	4.28	22.58	5.36
Huaiji, Guangdong	4.48	4.70	13.26	17.27	343	12.34	23.81	7.43	5.65	16.81	50.87	3.09	23.87	1.68
Qiongshan, Hainan	4.65	2.57	12.73	19.56	373	16.77	26.46	1.55	6.01	11.65	45.5	3.74	23.60	4.87
Nanning, Guangxi	4.38	1.47	14.08	10.94	313	9.54	25.26	2.34	6.12	20.59	46.16	1.73	22.21	4.59
Qingyuan, Guangdong	4.25	0.00	13.67	5.71	312	5.74	23.70	3.88	5.61	3.74	43.68	2.95	23.94	6.22
Xinyi, Guangdong	4.35	2.79	12.81	6.56	341	8.99	26.10	6.51	6.07	8.24	45.75	3.98	21.31	7.84
Zengcheng, Guangdong	4.31	0.94	13.46	4.23	320	4.06	25.04	5.79	6.13	9.62	45.48	9.26	22.05	7.85

Trend in geographical variation of bamboo wood properties

The correlation analysis between fiber dimensions, chemical components, and geographic and climate factors showed that fiber length became shorter with an increase in altitude (Table 5). The ratio of length to width (L/W) became lower with the increase of the latitude. There were significant negative correlations (α=0.1) between fiber dimensions, altitude and latitude, but the other traits did not follow any geographic trend. These results were in aggreement with previous studies. Ma and Zhu (1990) found that fiber length and ratio of L/W of *B. chungii* in the south of Zhejiang Province were smaller than those in low latitude regions. The variation of fiber dimension with latitude is an adaptation to its physical support function, i.e. the faster growing bamboo of lower latitudes (altitude) requires longer fiber length and higher ratio of L/W to support taller culmthan those growing at higher latitude (altitude).

Table 5. Correlation coefficients between bamboo wood properties and environmental factors

Index	Longitude	Latitude	Altitude	Annual mean temp.	Minimum temp.	Annual precipitation	Relative humidity	Frostless days	January monthly mean temp.	July monthly mean temp.
1%NaOH extractive	-0.465	-0.472	-0.160	0.273	0.320	-0.496	0.686+	0.323	-0.178	-0.241
Benzo-alcohol extractive	-0.437	0.062	0.246	-0.285	0.067	-0.144	0.026	-0.084	0.565	-0.767*
Fibrin	-0.106	0.302	0.224	-0.372	-0.437	-0.052	-0.066	-0.784*	0.552	-0.232
Lignin	0.240	-0.087	-0.301	0.035	0.308	0.322	-0.195	-0.164	-0.06	0.181
Fiber Length	-0.234	-0.540	-0.675+	0.355	0.220	-0.614	0.63+	0.243	-0.555	0.306
Fiber Width	-0.188	0.563	0.218	-0.552	-0.284	0.065	-0.863**	-0.138	0.447	-0.313
Ratio Of L/W	-0.063	-0.631+	-0.492	0.508	0.318	-0.376	0.823*	0.196	-0.531	0.323

Notes: $**,*,^+$ indicate statistically significant at 0.01 , 0.05 and 0.1 level respectively.

Three fiber dimension indexes (fiber length, width and ratio of L/W) had a close correlation with relative humidity (RH), i.e. there were significant positive correlations (α=0.05 and α=0.1) between fiber length and ratio of L/W with RH, and there were

very significant negative correlation (α=0.01) between fiber width and RH. The reason may be that high RH favors the growth and length of bamboo inter-nodes. Xing (2003) found that there was a negative significant (α=0.01) correlation between the number of node under the first branch and RH in *Dendrocalamus latiflorus*, which implied that less nodes developed with higher RH and that these conditions resulted in higher length of inter-nodes and increase fiber length and ratio of L/W.

There is no obvious geographic variation model in timber chemistry compositions, although there are some correlations between chemistry traits and climate factors. There is a significant negative (α=0.05) correlation between fibrin content and frostless days (FD). This result was consistent with the usual finding that slow-growing tree species have higher fibrin content compared with that of fast growing tree species. There was also negative significant (α=0.05) correlation between benzo-alcohol extract and July monthly mean temperature (Jul. MMT). The result suggests that higher temperatures might inhibit the growth of plants and organic compound constructive metabolism.

There were no significant correlations between fiber dimensions, timber chemistry composition and longitude, coinciding with the findings of similar research on *Pinus massoniana* by Zhou et al. (1995).

Genetic manipulation of timber characteristics for different traits

The broad-sense heritability of benzo-alcohol extract and fiber width could not be estimated because the variance due to provenance of the traits was less than that due to the environment. Heritabilities for other five bamboo wood traits, such as 1% NaOH extract, fibrin content, lignin content, fiber length and ratio of L/W were 0.54, 0.71, 0.38, 0.84 and 0.13, respectively. Obviously, most of the bamboo wood properties in this study were under medium or intense genetic control except the ratio of L/W, benzo-alcohol extract and fiber width. The results suggest that it would be effective to carry out direct selection for those high heritability traits in order to improve production and quality.

Selection efficiency for bamboo wood features will be improved by the indirect choice for growth trait or culm form trait if there are close correlations between the timber features and growth trait or culm form traits. Correlation analysis for growth amount and culm form traits (including DBH, height, clear height, node number under the first branch, culm number per clump) (Table 6) showed that the chemistry characteristics were independent from clear height and node number under the first branch. The 1% NaOH extract was significantly negatively correlated with culm number per clump (α=0.05). The correlation between fibrin content and DBH was significantly positive (α=0.1). There was no close correlation between lignin content and growth traits. The results show that these relationships between bamboo wood and growth or culm form traits are useful information for pulp-bamboo selection because of the decrease of extraction with the increase of bamboo output.

Stronger relationships between fiber dimensions and culm form traits were found in this study (Table 6). For example, there were significant (α=0.05) or very significant (α=0.01) negative correlations between fiber width and growth traits (DBH and height) or culm form index (clear height and node number under the first branch), and there was very significant negative correlations between fiber length and culm number per clump, significant (α=0.05) or very significant (α=0.01) positive correlations between L/M ratio and bamboo growth or culm form traits.

Table 6. Correlation coefficient between bamboo wood trait, growth trait and culm of *Bambusa chungii*

Index		1	2	3	4	5	6	7	8	9	10	11
1%NaOH extractive	1	1.000										
Benzo-alcohol extractive	2	0.247	1.000									
Fibrin	3	-0.331	0.065	1.000								
Lignin	4	-0.539**	-0.155	0.359+	1.000							
Fiber length	5	0.408	-0.101	0.047	0.060	1.000						
Fiber width	6	-0.047	0.071	-0.015	-0.203	0.036	1.000					
L/W	7	0.189	-0.095	0.031	0.248	0.354+	-0.915**	1.000				
DBH	8	-0.156	-0.219	0.346+	0.187	0.016	-0.620**	0.572**	1.000			
Height	9	-0.130	0.030	0.236	0.028	-0.174	-0.608**	0.480*	0.803**	1.000		
Culm	10	-0.512*	-0.340	-0.148	0.290	-0.635**	-0.075	-0.189	-0.069	0.001	1.000	
Clear heigh	11	-0.211	-0.119	0.072	0.164	0.002	-0.536**	0.483*	0.740**	0.626**	-0.039	1.000
Node number	12	0.148	-0.258	0.025	-0.203	0.094	-0.431*	0.435*	0.658**	0.621**	-0.194	0.641**

Notes: **,*,+ indicate statistically significant at 0.01, 0.05 and 0.1 level respectively.

Selection for optimal provenances of pulp-bamboo

Principal coordinate analysis was carried out with some of bamboo wood properties, main growth characters and yield feature with significant variance difference among eight provenances. The cumulative proportion of the first, second and third principal components exceeded 85%, what gives strength to the conclusions of this analysis (Table 7). The first principal component represents synthesis information of DBH, culm number per clump, clear height and 1% NaOH extract. The second principal component represents mainly the information of bamboo wood yield per clump and fibrin content, while the third principal component reflects fiber length and fibrin content contrast to height. The three-dimensional scatter plots of 8 *Bambusa chungii* provenances based on the first, second and third axis of principal coordinate analysis can be used to assess the quality of provenances for good pulp-bamboo (Fig. 2). The results suggest that Huaiji provenance is an optimum pulp-bamboo provenance with

high bamboo wood yield and fibrin content, growth amount and the lowest 1% NaOH extract. Guilin and Xinyi were the other two good provenances for developing pulp-bamboo stand bases.

Table 7. Eigenvector of selected principal components

Items	1%NaOH extractive	Fibrin	Fiber length	DBH	Height	Culm number per clump	Clear height	Node number	Yield per clump	Proportion (%)	Cumulative (%)
Prin1	0.3428	0.1634	0.3089	0.4321	0.3096	-0.4638	0.3362	0.3869	0.0022	47.3	
Prin2	-0.3393	0.5232	-0.2981	0.2083	0.2849	0.0902	-0.0001	-0.0385	0.623	26.9	74.27
Prin3	0.1712	-0.4141	-0.5867	-0.1154	0.4893	0.2054	0.1037	0.3853	-0.0308	10.98	85.25

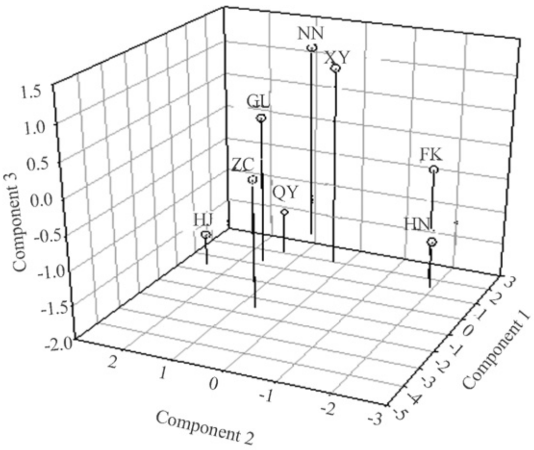

Fig. 2 Scatter plots of 8 *Bambusa chungii* provenances based on first, second and third components of principal coordinate analysis

Discussion

Bamboo has already been used for papermaking in China for a long time; for instance, Xuan paper (a representative bamboo product) emerged in the Chin Dynasty. Previous studies showed that the performance of bamboo paper is superior to that from grasses, and just similar to that from broad-leaf trees, although it is inferior to that from conifers (Yang et al. 2002). According to this study, *B. chungii* could belong to top-class resource material for paper-making in bamboo species with features of fiber length more than 4 mm, ratio of L/W over 300%, HNO_3^-alcohol fibrin content exceeding 44%, lignin content less than 26% (Hui et al. 1996)

Zobel (1971) found wood density, branch diameter and stem straightness were affected by genetic factors in loblolly pine (*Pinus taeda*). Also, families with characteristics of fast-growth and high-density have been selected based on the knowledge of Zobel. Extensive variance in wood properties was found in poplar (Jiang et al. 1994), spruce (Yanchuk et al., 1992), *P. massoniana* (Zhou et al. 1995), *Larix kaempferi* (Sun et al. 2003), *Cunninghamia lanceolata* (Sun et al. 1993). So, the utilization of the genetic variance is one of the main tasks of forestry genetic improvement. However, there are few study on intraspecies geographic variation of bamboo wood properties. In this study, some chemical composition variances were found for the first time among *B. chungii* provenances, optimum provenances with desired features could be selected, and some chemistry traits varied markedly among individuals but not among provenances. For those traits the selection of individual plants can be a good choice. The selected individual can be extensively utilized by large-scale cloning propagation.

Geographical origin is sometimes one of the best indicators of genetic performance because the difference occurs in chemical composition of wood in different geographical origin. Take Oak Barrels as example, the species from United States and France can be easily distinguished from each other by the detection of chemical composition of wood. Most of the species from France can be unambiguously assigned to their actual classes of geographical origin even though they were collected from neighboring forests (MARCO et al. 1994). In this study, fiber length and ratio of L/W in *B. chungii* have decreasing geographical trends from south (low altitude) to north (high altitude) in China. Our study result is agreed to previous studies (Wang et al. 2007; Harris 1965). Generally, there was no significant correlation between the fiber morphology and longitude. Piedra et al. (1986) found that the differences in tracheid length had no significant changes in mature *P. tecunumanii* from east to west. For latitude, *B. chungii* behaves in a similar way as *P. tecunumanii*. So, the conclusion suggests that the researchers should pay more attention to changes of fiber characters when introducing *B. chungii* from south to north to ensure that the new plantation keeps its genetic superiority.

Wood properties are assumed to be under the control of multigene families. As a result of that, there are different degree of correlations among wood properties and other traits. When considering wood properties for tree improvement programs, the interaction among them and with other traits should be investigated. Correlation coefficients between microfibril angle and wood properties showed that they have a significant negative relation in poplars (α=0.01; Fang et al. 2004). There was a strong or moderate negative genetic relationship between diameter growth rate and wood density in *Picea glauca* (Carriveau et al. 1987) and others. In our study, relationship between bamboo traits and properties for *B. chungii* was investigated for the first time, providing useful information for the selection of genetic materials for paper-making.

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